CHAPTER 2 -- INTRODUCTION TO LOADING-RACK METERING SYSTEMS

OBJECTIVES

After studying this chapter, and reviewing its contents with your instructor, you will be able to:

1. Identify loading-rack meters as a class of liquid-measuring devices distinct from other devices covered in the Liquid-Measuring Devices Code of NIST Handbook 44.
2. Identify the major types of loading-rack installations and describe the distinctive features of each.
3. Identify and describe the major functional components of a typical loading-rack meter system.

INTRODUCTION

It was said in the last chapter that loading-rack meters are commonly used in the commercial transfer of petroleum products (and many other liquid commodities) at the wholesale level, and that they are employed in the measurement of product that is delivered by the seller to the buyer. It was also said that regulation and inspection of these devices is an important function of State and local weights and measures jurisdictions. It may seem surprising, then, that the term "loading-rack meter" does not occur once in the Liquid-Measuring Devices (LMD) Code, or elsewhere in NIST Handbook 44.

You will see that this omission is a matter of practicality in framing the uniform regulations: loading-rack meters, despite their similarity to other devices covered in the LMD Code, do constitute a distinct class of devices and deserve to be treated separately, particularly in inspection and test procedures. Since there is no legal definition of the term in Handbook 44, we will begin by describing the characteristics of devices to which the designation appropriately applies, and then look at how this class corresponds with the categories of devices in the LMD Code.

Many liquid commodities travel long distances between the refinery or processing plant at which they are produced and the place at which they are sold to retail customers. Of course, product does not flow directly from the refinery or plant to individual homes or factories; it is transported in large quantities to bulk storage and distribution facilities. These facilities, commonly called <u>terminals</u>, are usually located on major transportation arteries or nodes, so that large shipments can efficiently be delivered by tanker ship, barge, or pipeline (or by truck or rail, although these carriers are usually not as efficient for very large deliveries).

Depending upon its final destination, the product may then be transported to smaller bulk facilities, which serve smaller areas or populations.

Since we are going to focus on petroleum products, consider the familiar example of home heating oil. In most parts of the country where heating oil is used, it is delivered to homes by tank truck. Usually, the owner of the truck is independent of the oil company, and has himself purchased the oil he sells to individual homeowners at wholesale from a larger distributor. The wholesale transaction generally occurs at a bulk terminal, where the truck is filled and the truck owner charged for the quantity he receives, usually based upon a pre-agreed contract price per gallon.

The truck is driven into the facility and parked adjacent to an island or platform, as shown in Figure 2-1. On this island are one or more discharge lines, a meter and a register for each discharge line, and other equipment. The island generally has an overhanging roof to protect the equipment from the elements. A discharge line is connected to the inlet of the truck tank (at the top, side, or bottom, depending upon the design of the truck) and product is pumped into the tank.

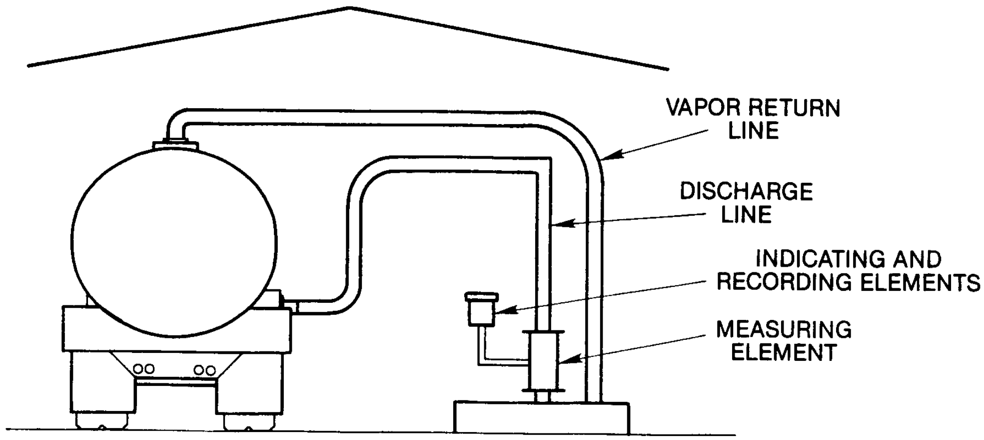


FIGURE 2-1. Loading rack.

All product that is delivered to the truck tank passes through the meter, so while the truck tank is filling, the meter and register simultaneously measure and indicate the quantity of product delivered. If the product being metered is volatile, a vapor recovery line (usually a semi-rigid hose) may be provided to carry hazardous vapors away from the area. When the tank is full, product flow is shut off and the reading on the register (or on a printed ticket generated by a recording device) is used as the basis for determining the total price of the product to be charged to the buyer.

The island or platform, along with the equipment used for metering, is the loading rack (so called, perhaps, because the discharge lines and metering equipment appear to hang from the framework of scaffolding, piping, and platform, as if on a rack). Loading racks are also used for deliveries to railroad tanker cars, barges, and similar carriers.

Although most often used for wholesale deliveries, loading-rack metering systems can also be used for retail service. However, keep in mind that the definitions of 'wholesale' and 'retail' devices established in NIST Handbook 44 are based upon specific service characteristics rather than whether or not the device is used exclusively -- or even primarily --for sales to final purchasers. Note the following quotations from the Definitions section of Handbook 44.

retail device. A device used for:

single deliveries of less than 378 L (100 gallons),

retail deliveries of motor fuels to individual highway vehicles, or

single deliveries of liquefied petroleum gas
for domestic use and liquefied petroleum gas
or liquid anhydrous ammonia for nonresale use.

Retail and Wholesale Devices as defined in
DEFINITIONS section of NIST Handbook 44

The vast majority of loading-rack meters in commercial service at this time do not meet any of the Handbook 44 conditions for a retail device. In this module, therefore, loading-rack meters will be considered to be wholesale devices for the purposes of this definition. Note that the Liquid-Measuring Devices (LMD) Code in Handbook 44 has separate requirements for wholesale and retail devices. If you are examining a device that meets one of the definitions of a retail device, the requirements applicable to that device may be different from those described in the following chapters.

As you will see, the design and operating characteristics of the measuring and indicating elements of loading-rack metering systems are quite similar to the corresponding elements of other classes of liquid-measuring devices, such as gasoline pumps, vehicle-tank meters (like those installed on fuel oil trucks), LPG liquid meters, agri-chemical meters, and so on. Why, then, should loading-rack meters be considered as a separate class of devices, to which distinct requirements and examination procedures are applied?

Most loading-rack metering systems operate at discharge rates that are considerably higher than those of liquid-measuring devices used in applications where the receiving tank is smaller: gas pumps typically operate at rates between 8 and 15 gallons per minute (gpm), vehicle-tank meters between 40 and 100 gpm, many loading-rack meters at rates from 500 to 1,000 gpm, or higher. However, their accuracy and repeatability are comparable to smaller meters. And loading-rack meters, like most of the others named, are commonly used for measuring petroleum products in liquid form (as well as other liquid commodities sold from bulk terminals, such as anhydrous ammonia, agri-chemicals, and industrial chemicals).

In fact, the reason for distinguishing these various classes of liquid-measuring devices from one another has very little to do with the measuring and indicating elements -- the meter and register -- but with the differences in operating characteristics of the <u>delivery systems</u> in which they are installed.

In examining these devices in the field, you will focus your attention on the measuring, indicating, and recording elements of the system, and you will compare observed "meter errors" with applicable tolerances when you conduct performance tests. However, it is essential that you understand that the measuring, indicating, and recording elements are individual components of a <u>system</u> and that their performance depends to at least some degree upon the operation of other components, which may directly and substantially affect measurement accuracy.

For example, an important factor that can affect the accuracy of any metering system is the presence of air or vapor in the liquid product as it flows through the meter. These gases will be measured by the meter as though they were liquid, and the buyer will, in effect, be paying for product that he has not received. Vapor is a special concern in the case of gasoline, aviation fuel, and other petroleum products that are relatively volatile (that is, they tend to vaporize readily at atmospheric pressure). As you will see, air and/or product vapor can be introduced at many points in the system, and care must be taken to design and install components to minimize air/vapor production and eliminate any that is produced.

All loading-rack metering systems have components that perform one of four basic functions:

- product storage
- piping and control for product supply
- product measurement and indication of quantity
- delivery of product to receiving tank

The rest of this chapter will be devoted to a description of the loading-rack metering system and its major components. In the next chapter, we will look more closely at the operation of specific elements, especially the measuring, indicating, and recording elements.

PRODUCT STORAGE

Figure 2-2 illustrates the major components of a loading-rack metering system: storage tank, pump, piping, strainer, measuring element (meter), indicating and recording elements (register, ticket printer), flow control valves, and discharge line. Several other elements shown in Figure 2-2 are described below. Like many of the drawings in this module, this one is intended to illustrate typical features, and is somewhat simplified.

Product is stored in tanks, which can range in capacity from a few thousand gallons to several hundred thousand gallons, depending on the size of the installation. Of course, each tank contains only one product, but a single facility may have dozens of storage tanks.

Storage tanks may have either fixed or floating roofs. The latter design, which is relatively newer, minimizes loss of product in the form of vapor, since the roof literally floats on top of the liquid product, leaving no head space in which vapor can form.

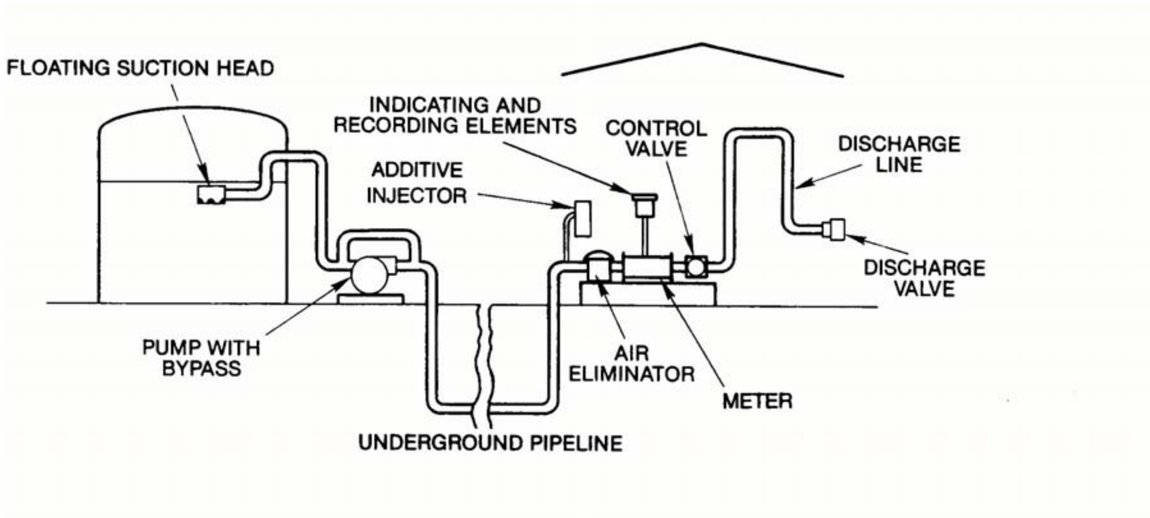


FIGURE 2-2. Loading-rack metering system.

PRODUCT SUPPLY AND FLOW CONTROL

A pump draws product from the tank through a suction head. In older systems, the head would be fixed somewhere near the low-level line of the tank. In newer designs, the suction head is submerged below the liquid surface, but is attached to a buoyant device, and may rise and fall with the level of product. When a liquid is drained from an outlet at or near the bottom of a container, there is a tendency for a vortex to form (the "whirlpool" you see when you drain a sink or bathtub is a vortex). When a vortex is formed, air (or, in the case of a petroleum tank, air and vapor) from above the liquid surface travels down the vortex and passes into the drain. Maintaining the position of the suction head near the surface of the liquid prevents the formation of a vortex, and thus makes it possible to draw product with relatively little risk of drawing air and vapor into the flow.

The pump that draws product from the tank and propels it toward the loading rack is usually located as close as possible to the tank. Minimizing the length of piping on the suction side of the pump helps avoid vaporization in the pipeline, and precludes leaking of air into the product flow, since product on the discharge side of the pump is under positive pressure (so air can not enter through a leak).

The pump is generally equipped with a bypass circuit, which permits product to recirculate if the pump is activated but product is not being discharged. This reduces strain on the pump. However, the pump should not be left running continuously while the system is not delivering product, since recirculating product tends to heat it, which encourages vaporization.

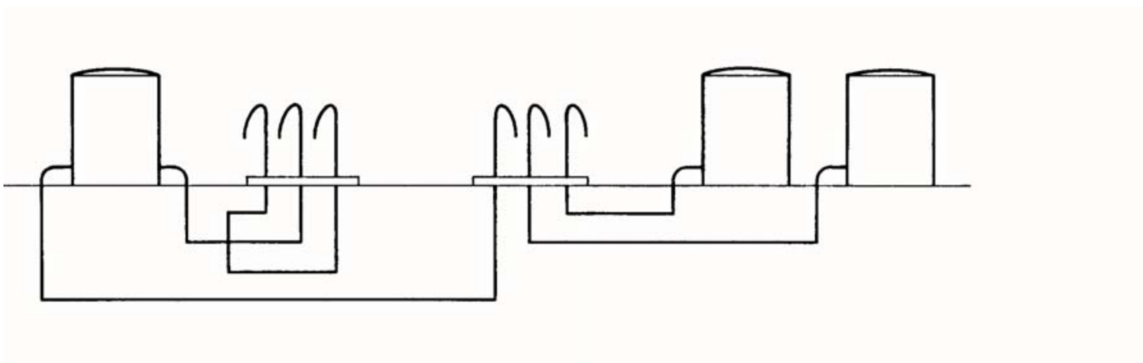
The pipeline between the storage tank and the loading rack may be underground. This minimizes the effects of ambient temperature or radiant heat on the product, but makes leaks much more difficult to locate and repair. Concern about environmental pollution from undetected leaks has led many facilities to install aboveground pipelines in recent years. The pipeline should be as straight as possible and avoid upward pitches (where vapor may be produced). For the same reason, valves should be kept to a minimum, and should be limited to designs that create minimal restriction when open.

It is, however, often necessary to install one or more check valves in the product line. These permit product to flow only in the direction of the system discharge (toward the loading rack), not backward toward the storage tank. These valves serve to maintain pressure in the pipeline even when the pump is not on, avoiding vaporization due to temperature fluctuations and preventing air from entering the liquid through leaks.

The system may also be equipped with service valves, which are used to isolate sections of pipeline or other components in the flow path for repair or replacement. Excess-flow valves may also be incorporated in the design as a safety feature. These valves, which automatically close when the flow rate across them exceeds a preset amount, prevent an uncontrolled discharge in the event of a rupture downstream of the valve.

Several different discharge lines may draw product from a single pipeline. In that case, they will be connected in parallel, as shown in left-hand drawing in Figure 2-3, to minimize pressure fluctuations if deliveries are started and stopped from two or more lines. Similarly, different pipelines may serve the same loading rack (as shown in the right-hand drawing, permitting multi-compartment trucks to load different products simultaneously.

Many sellers of petroleum products combine special additives with the basic product, proprietary formulas that may be represented as power- or mileage-boosters, cleansers, lubricants, demoisturizers, and so on. (Additives



make different brands of gasoline different from one another.) These chemicals are relatively expensive, and to minimize waste from evaporation, the additives are injected into the product after it has left the storage tank.

FIGURE 2-3. Pipeline connection to loading rack.

Additive injectors are not directly involved in measurement or delivery of product, and so are normally of no concern to the weights and measures inspector. However, additives should be introduced into the product before it passes through the meter, so that they will be measured along with the liquid product. Also, additives may affect the physical properties of the product, and their presence or absence could significantly affect test results (if, for example, the operator switches off the additive injector prior to a weights and measures examination).

Before product enters the meter it passes through a strainer, which traps solid particles that could damage the meter if allowed to pass through it, or contaminate the metered product. The strainer should be removed, checked for holes, and cleaned periodically as part of the routine maintenance of the equipment. An accumulation of solid material in the strainer can restrict flow, creating the potential for vapor production just before the meter.

Some loading-rack into metering systems are equipped with an air/vapor eliminator, which is usually located at or near the inlet of the meter. The function of this component is to separate from the liquid any air or vapor that has been introduced into the liquid product before it enters the meter. Air or vapor collected by the eliminator is vented, either to the atmosphere or a device that condenses product vapor.

Not all loading-rack metering systems are equipped with air eliminators. If a system is so designed that significant amounts of air and/or vapor can not be produced, an air eliminator is not necessary, and you will encounter many systems that do not have them. We will look more closely at the operation of the air/vapor eliminator in Chapter 3.

Most systems are equipped with an automatic flow control valve, which may be located either near the inlet or the outlet of the meter. This valve regulates the discharge rate throughout the delivery, keeping it low at the beginning of the delivery, reducing it at the end, and allowing full flow in between. For example, the control valve might reduce the flow rate for the first 300 gallons and the last 50 gallons of a 1,000-gallon delivery. This is an important function, for a number of reasons.

First, many loading-rack meters operate at maximum discharge rates of more than 500 gpm, some at rates in excess of 1,000 gpm. Liquid flowing at this velocity has a great deal of force. A slow startup protects the meter from hydraulic shock, which can accelerate wear that will ultimately affect accuracy.

A relatively slow flow rate at the start of the delivery also reduces turbulence and splashing in an empty receiving tank, which can produce large quantities of vapor from metered product, especially from gasoline or other volatile liquids. This vapor is either recovered by the seller (if the system is set up for vapor recovery) or lost to the atmosphere. In either case, even if the meter accurately measures the liquid that passes through it, the purchaser will receive -- and have to pay for -- less than the measured amount. Although some vaporization will occur anyway, a slow startup minimizes this loss. After the bottom of the tank and the inlet (or fill spout, see below) is covered with product, vaporization drops off substantially, even when the discharge rate is increased to the maximum.

Turbulence and splashing at the beginning of a delivery also tend to produce static electricity. So a slow startup lessens the hazard of static discharge inside the tank, where there may be a potentially dangerous mixture of air and flammable vapors.

A relatively low flow rate at the end of a delivery also reduces hydraulic shock, in contrast to an instantaneous shutoff from full flow. As you will learn in Chapter 4, it also serves an important safety function when the system is being tested, permitting the operator to monitor the rising liquid level in the prover with the flow rate low enough to allow a manual shutdown if an overfill is about to occur.

The control valve functions with a device called a quantity preset to perform these functions automatically (we'll look closely at the operation of these components in the next chapter). As you will learn, meter performance can be expected to vary with the discharge rate. So, the regularity of the flow control from one delivery to the next helps to assure repeatability.

Auxiliary devices, such as manual (emergency) shutoffs and overfill sensors are often connected to the flow control valve. We will look more closely at these auxiliary devices in the next chapters.

MEASUREMENT AND INDICATION OF QUANTITY

We now come to the measuring and indicating components of the system. Liquid product is measured as it passes through the meter. The mechanical action of the meter is transferred, either mechanically or electronically, to the register, which continuously "counts" and displays the total quantity delivered in units of measure.

The meter and register are the basic measuring and indicating elements of the system, and Handbook 44 requires that all systems be equipped with them. Auxiliary devices, such as invoice printers and quantity control presets, are not required, but many systems have them.

Many loading-rack metering systems are also equipped with thermometers, or similar devices that sense and indicate the temperature of product in or immediately adjacent to the meter. These are used to adjust the volume indicated by the register to the volume that the same quantity would occupy at the product's reference temperature (for example, the reference temperature for petroleum products is 60 /F). These adjustments may be made manually, with the help of petroleum measurement tables. However, many loading-rack systems are now equipped with automatic temperature compensating systems (ATCSs), devices which perform the adjustment and display the compensated (or "net") quantity without any action by the device operator.

The practice of compensating for variations in product volume due to temperature is now common in many parts of the country. But temperature compensation is an appropriate and equitable practice only when it is employed constantly, not just when adjustment benefits the device operator or owner. For example, in the case of petroleum products it is not equitable to adjust indicated volume only in the winter, or at times when the product temperature is likely to be below 60 /F. The practice of temperature compensation, and the devices used for this function, have become major concerns of weights and measures regulation. As you will learn, a number of specific regulations concerning temperature compensation and automatic temperature compensators have been added to Handbook 44 in recent years.

In order to perform accurate temperature compensation, the density, or specific gravity of the liquid must be known. ATCSs must have some means of adjustment for variations in the density of the product, which is checked periodically, making it possible for the operator to reset the ATCS as necessary.

We will take a closer look at the meter, register, and other elements directly associated with measurement and indication of quantity (such as invoice printers and temperature and gravity compensators) in Chapter 3. For now, we will pass over these important elements, and consider several important features of the discharge line.

DELIVERY TO RECEIVING TANK

The discharge line carries product from the meter to the receiving tank. Most loading-rack meters have "wet" discharge lines. This means that at the conclusion of the delivery the discharge line remains filled with product, which is trapped between the meter and a valve at the outlet of the line. (This is sometimes referred to as a "packed line" or "packed hose".) This valve at the outlet of the discharge line is not generally used to control or halt the delivery (that is done by the control valve, described above, governed by the preset and manual shutoff, etc.). Since this quantity of product has been metered, the line must remain packed between deliveries, so that the next customer will receive a quantity of metered product at the beginning of the delivery that is equal to the amount that will be left behind at the conclusion.

"Dry" discharge lines are only used in installations where the discharge line can be drained completely at the conclusion of the delivery, so that no product is left behind. A dry hose must not have a valve at its outlet (such a valve would facilitate fraud), must be rigid or semi-rigid, and must not be capable of retaining any liquid. Systems that employ pumps to discharge product (as virtually all systems now in operation do), or that load product though the side or bottom of the receiving tank, can not efficiently use a dry discharge hose, so the dry hose is rarely encountered, except in top-loading systems, as described below.

Loading racks are designed to fill receiving tanks either from the top, or from the side or bottom, and this classification (top fill vs. side/bottom fill) is a significant one.

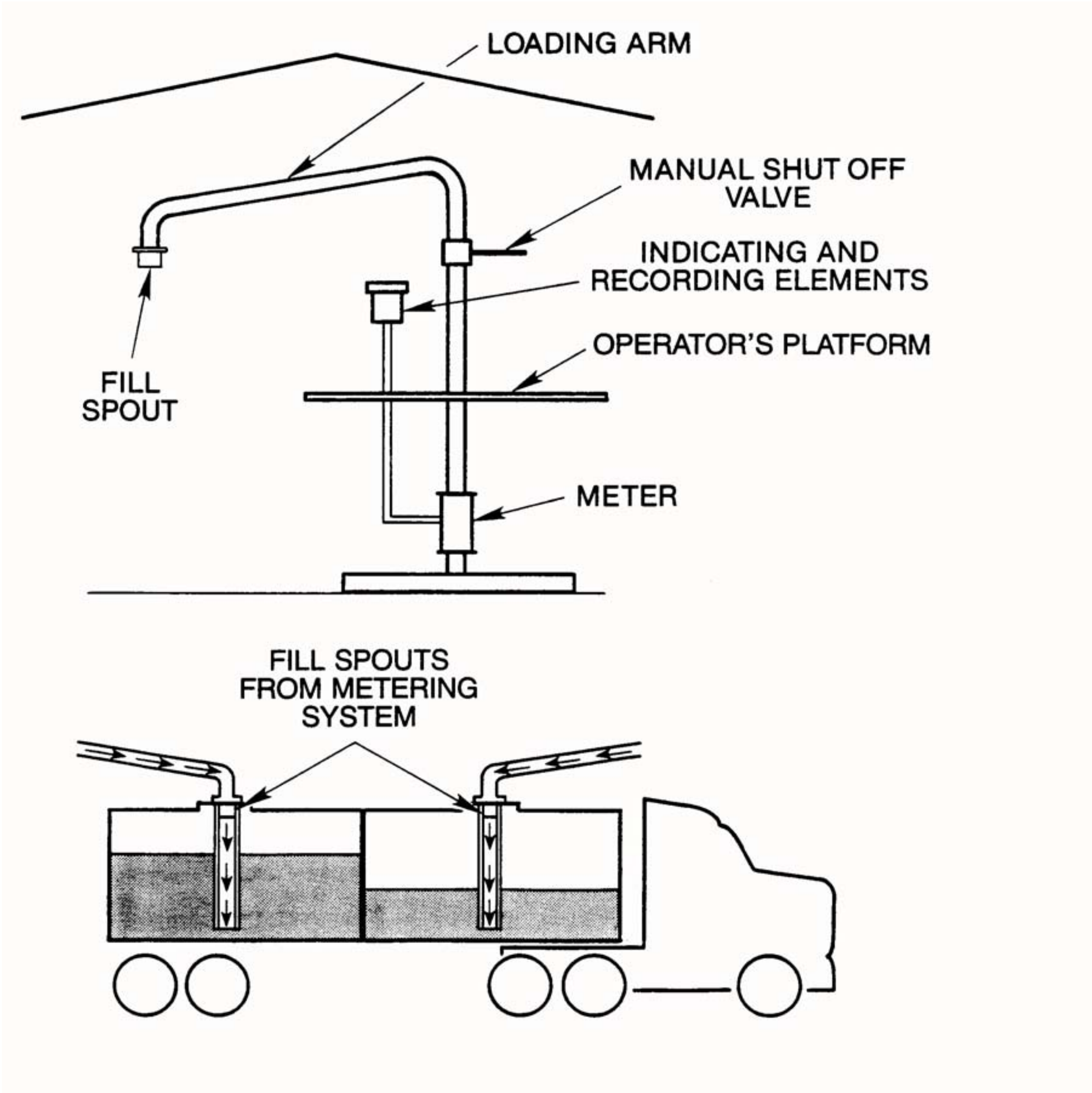


FIGURE 2-4. Top loading.

Until relatively recently, most vehicle tanks were designed to be filled through an inlet at the top, as shown in Figure 2-4. Because top-fill trucks are still in operation, this method of loading, and this type of loading rack, are still found.

On a top-loading system, vertical piping carries product from the meter to a movable loading arm, which can be swung out over the top of the tanker to align the discharge line with the tank inlet. A rigid tube, referred to as a downtube or fill spout, attached to the end of the discharge line, is then lowered into the receiving tank. The purpose of this tube is to minimize splashing and resultant vaporization, foaming (especially in heating oil and similar products), and static buildup. At the conclusion of the delivery, when product flow has ceased, the fill spout is carefully raised from the receiving tank and allowed to drain completely into the tank.

Insofar as the fill spout is an extension of the discharge line, top-loading systems might be thought of as having partially dry-hose and partially wet-hose discharge lines: the fill spout is dry, and so must be drained completely between deliveries; however, the piping between the meter and the end of the loading arm, where the fill spout attaches, is wet, and must be kept packed between deliveries. The valve at the end of the loading arm must therefore seal the wet line completely at the moment when the delivery ends, since any additional liquid passing through will be drained into the receiving tank.

Most new tank trucks are designed for side or bottom fill, as shown in Figure 2-5. Although loading from the side or bottom of the tank produces less splashing and turbulence, especially when product has covered the inlet, many tanks are also equipped with deflectors or other devices to reduce agitation.

As illustrated in Figure 2-5, the loading arm for a side/bottom-loading system is designed so that the discharge end can connect directly to an inlet fitting on the lower portion of the truck. Because of this, the operator usually works at pavement level, rather than on an elevated platform, and the register and other indicating and recording elements are also located at pavement level.

The "dry break" coupling has become standard for side/bottom fill systems and the trucks they supply. It is a quick-connect/disconnect type coupling, which securely seats and seals itself when pushed into position by the operator. Dry break couplings are designed to minimize spills during disconnect. This device is described in greater detail in Chapter 5.

Regardless of the loading method (top or side/bottom fill), some quantity of vapor is likely to be produced. The rising liquid level in the bottom of the receiving tank as it is being filled acts like a piston, displacing the vapor that is produced during loading, along with air and/or residual vapor that was in the empty tank.

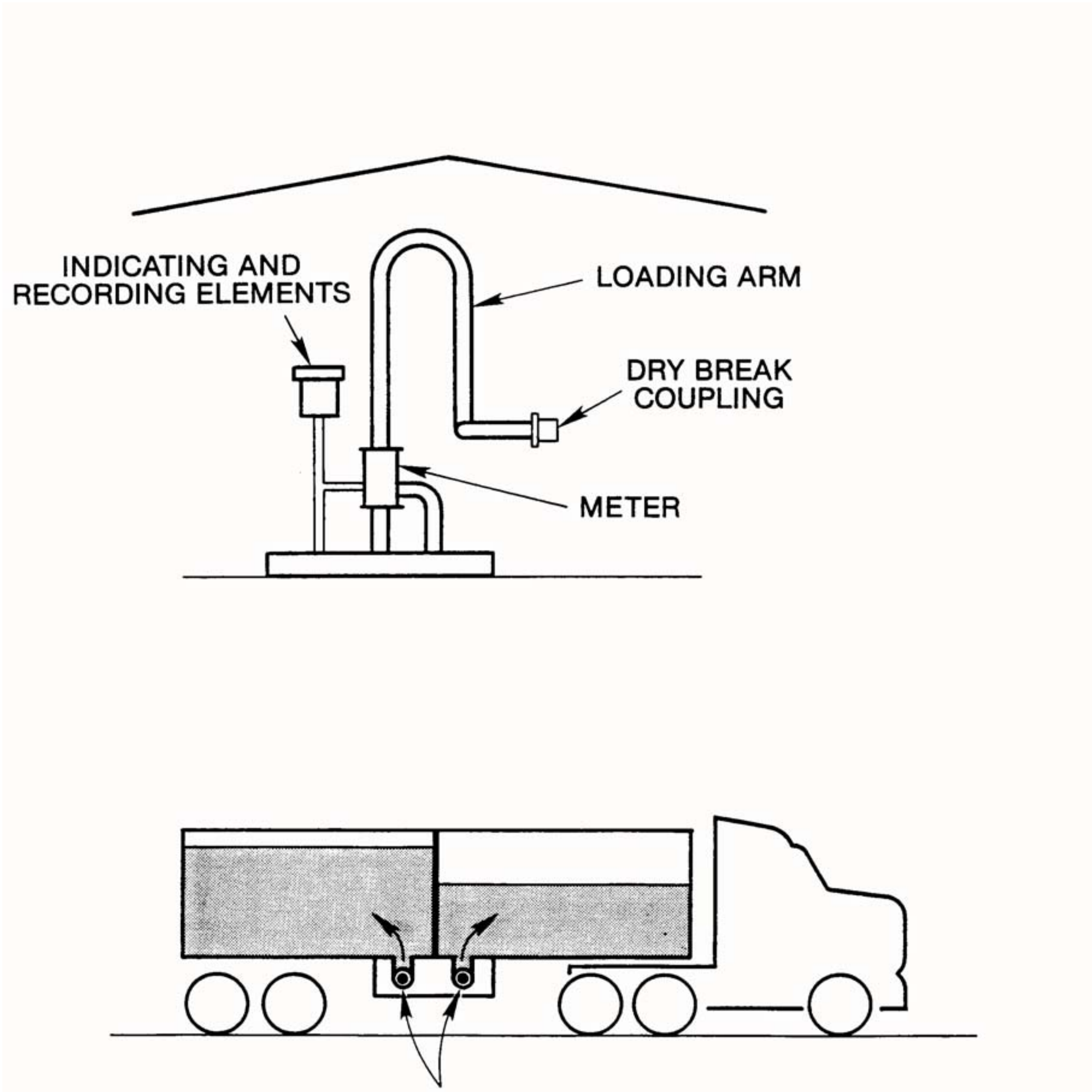

INDICATING AND
RECORDING ELEMENTS
LOADING ARM
DRY BREAK
COUPLING
METER

FIGURE 2-5. Side/bottom fill.

Because the actual loss of liquid product to the purchaser from vaporization in the receiving tank might be considered relatively insignificant -- probably not more than 0.1 percent of the total delivery of a product like gasoline (or less than 1 gallon lost for a 1,000-gallon delivery), if reasonable care is taken -- until recently, these gases were simply vented through the top of the tank to the atmosphere.

However, concentrations of flammable vapors above the tank could present a risk of explosion. While the actual risk of an explosion may be quite small in most installations, loading-rack operators, especially those standing on the platform above the tanker, would be exposed to the vapors for extensive periods. Recent studies suggest that such exposure can have serious long-term health hazards. There is also concern about general pollution of the atmosphere.

Because of these concerns, many loading racks have been equipped with vapor-recovery systems in recent years (in some jurisdictions they are required by law). As illustrated in Figure 2-1, a hose is attached to a vent at the top of the receiving tank, which is otherwise closed to the atmosphere during the delivery. The gases displaced by the rising liquid level pass into this line rather than into the atmosphere, and may be collected and disposed of appropriately -- condensed to liquid and returned to the metering system product storage, burned off (where permitted), and so on. Suction should not be used to draw off tank vapor, since a decrease in pressure on the surface of the liquid product will only encourage more vaporization.

These are the basic components of a loading-rack metering system. Their design, size, and configuration may differ from one system to another, and some components, like the air eliminator, will not be found on all systems. As you acquire experience in the field, you will learn to recognize the numerous variations of the basic system described in this chapter.

SUMMARY

Loading-rack meters are liquid-measuring devices employed at bulk storage facilities primarily to measure wholesale deliveries of liquid commodities to receiving vessels. They are commonly used for wholesale sales of petroleum products to retail suppliers or other distributors, and it is in this application that they have the greatest economic impact and thus are of greatest interest to weights and measures regulation and enforcement.

Loading-rack metering systems typically have considerably higher discharge rates than other devices covered by the LMD Code that are similar in design and function (gas pumps, vehicle-tank meters, etc.). However, they are distinguished as a separate class of devices because of the characteristic operating features of the delivery systems of which they are a part.

All loading-rack metering systems incorporate storage tanks; supply line components (pump, piping, valves, strainer, etc.), measuring and indicating components (including meter, register, and auxiliary elements), and delivery components (primarily, the discharge line). The design, size, and configuration of individual components may vary, and not all are found in every system. However, the basic functions and interactions of these components are common to all systems.